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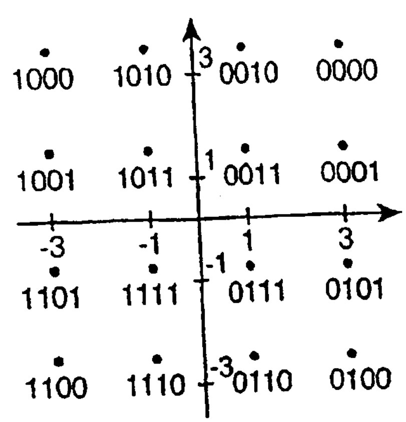
(54) Title: DEMODULATOR CIRCUIT



(57) Abstract: The invention relates to a demodulator circuit in a communication system using a multi-carrier modulation scheme. The demodulator makes efficient use of channel state information for respective carriers in the multi-carrier modulation to de-map the received data. An efficient method of calculating channel state information is also disclosed.

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DEMODULATOR CIRCUIT

TECHNICAL FIELD OF THE INVENTION

The present invention relates to a demodulator circuit in a communication system using a multi-carrier modulation scheme. The invention relates in particular to the effective demodulation of a received signal in a COFDM demodulator for a digital television receiver.

DESCRIPTION OF RELATED ART

Recently there has been a rapid development in the field of digital television broadcasting following the establishment of the European Digital Video Broadcast standard for digital terrestrial television (DVB-T) developed by the Digital Video Broadcasting Group.

In accordance with the DVB-T standard, a number of carrier frequencies are provided and data to be transmitted is spread over a large number of orthogonal data carriers using Coded Orthogonal Frequency Division Multiplexing (COFDM).

Each carrier can be encoded to carry a symbol containing more than one bit, for example by using a rectangular constellation modulation system such as 16-QAM, as is known to a skilled person.

An exemplary 16-QAM constellation diagram is shown in Figure 1. As is known to a skilled person, each point on the 16-QAM constellation diagram corresponds to a 4-bit symbol. The symbols are normally assigned to the constellation points using Gray coding, in which symbols with similar most significant bits are grouped together.

At the transmitter the carriers are modulated in accordance

with successive symbols to be transmitted and each received signal is demodulated in the receiver to the corresponding symbol using the constellation diagram. In most cases the signal received will not correspond exactly with a constellation point because of interference or noise in the channel between the transmitter and the receiver. In this situation the receiver must demodulate the received signal to the symbol corresponding to the constellation point which is most likely to have been transmitted.

It is known to de-map signals using soft decision decoding in which instead of a "hard" decision as to whether a bit should be decoded as a "1" or as a "0", a "soft" decision, comprising the hard decision and an indication of the level of confidence to be placed in the decision is output.

In simple systems the level of confidence which can be placed on the demodulated or de-mapped information is proportional to the distance or separation of the received signal from the expected constellation point. Clearly, the closer the received signal is to a constellation point, the more confidence can be placed in the de-mapped symbol.

When Gray coding is used, the level of confidence that can be placed in a particular de-mapped bit varies from bit to bit within the symbol.

The information from the de-mapper is passed to a Viterbi decoder which decodes the bits.

This soft decision information can be input into a soft decision Viterbi decoder. A soft decision Viterbi decoder maintains a history of many possible transmitted sequences and builds up a view of their relative likelihoods. The Viterbi decoder selects a "0" or a "1" as the decoded bit

based on the maximum likelihood. In this way the Viterbi decoder can exploit information relating to the expected reliability of each bit based on the proximity of each bit to the expected constellation point.

One problem with television broadcasting is the existence of multi-paths arising either as a result of the reception at the receiver of multiple copies of the signal emitted from a single transmitter, or as a result of the reception of signals from a number of transmitters all broadcasting the same signal. In the frequency domain, the existence of multi-paths is equivalent to a frequency selective channel response.

Furthermore, in situations where conventional analog television signals are transmitted within or overlapping the frequency range used by the digital television signal, the conventional analog television signals act as narrow interfering signals within the signal bandwidth of the digital television signal.

This frequency selective channel response characteristic results in the large number of different carriers used in COFDM modulation having different signal to noise ratios (SNR). Clearly, data conveyed by carriers having a high SNR is likely to be more reliable than data conveyed by carriers having a low SNR.

An estimate of the SNR of each carrier made by the receiver is called the channel state information (CSI) for the channel represented by that carrier. Figure 2 illustrates a typical variation in carrier CSI for a COFDM signal with co-channel analogue television interference.

One known method of establishing channel state information

for a COFDM signal is disclosed in the article "Demapping method using the pilots in COFDM system" IEEE Transactions on Consumer Electronics, Vol 44 No.3 Aug. 1998 pp 1150-1153. This method utilises the fact that pilot carriers with known magnitudes are transmitted with the COFDM signal, for equalisation purposes. An estimate is made of the mean square error in the magnitude of the received pilot carriers and channel state information in the pilot carrier positions can be obtained from this estimate. The channel state information in useful data positions can be obtained by subsequent interpolation between the values calculated at the pilot carrier frequencies.

In order to provide robust performance of the system in an environment having a frequency selective channel response, it is known to use the channel state information in the Viterbi decoder when decoding the bits in order to provide extra information regarding the reliability of the bits based on the signal to noise ratio of the carrier.

The article "Performance analysis of Viterbi Decoder using channel state information in COFDM System" IEEE Transactions on Broadcasting, Vol 44 No.4 Dec.1998 pp 488-496, describes a Viterbi decoder which uses Channel State Information calculated from a mean square estimation of the received pilot carrier signals in a COFDM system, to affect the Viterbi decoder branch metric values used to decode 3 or 4 bit soft decision data.

Previously it has also been suggested that if the channel state information of a particular channel is sufficiently bad, it can be concluded that no reliance can be placed on the data received on that channel. As a result, the Viterbi decoder may effectively record that no information is available regarding that bit by disregarding, or

"puncturing" the corresponding bit or bits.

The transmitted data is coded using a convolutional code, which introduces redundancy in the signal in order to allow error correction of the signal to be achieved. The effect of the puncturing of data bits in the Viterbi decoder as indicated above, is merely to reduce the effective code rate of the signal. If a sufficiently robust code is used, the effective reduction in code rate resulting from the puncturing of bits can be tolerated, thus avoiding an impact on the decoded signal quality.

SUMMARY OF THE INVENTION

Previously known demodulator circuits are complex since the calculated channel state information must be fed forward to the Viterbi decoder through the deinterleaver.

In addition, the previously known methods of calculating CSI from a received signal are computationally intensive.

The invention seeks to at least alleviate some of the problems associated with the previously known arrangements.

In particular the invention provides means for demapping data effectively using channel state information.

In addition, an effective method of calculation of channel state information for carriers in a multi-carrier communication system is disclosed.

In accordance with a first aspect of the invention, there is provided a demodulator circuit for demodulating a multi-carrier modulated signal, having de-mapping means for de-mapping the received signal to generate decision data, the decision data being generated in a manner dependent on

channel state information for the respective signal carrier; and a decoder for decoding the received bits from the decision data received from the de-mapping means.

In accordance with a second aspect of the invention, there is provided a receiver circuit for receiving a multi-carrier modulated signal, comprising means for establishing channel state information for the carriers of the multi-carrier modulated signal from the displacements of received signals on that carrier from the corresponding nearest expected signal, over a number of received signals.

In accordance with a third aspect of the invention, there is provided a method for demodulating a multi-carrier modulated received signal, comprising the steps of: de-mapping the received signal to generate decision data, the decision data being generated in a manner dependent on channel state information for the respective signal carrier; and decoding received bits from the decision data received from the de-mapping means.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present invention, and to show how it may be brought into effect, reference will now be made, by way of example, to the accompanying drawings, in which:

Figure 1 is an exemplary diagrammatic representation of a 16-QAM constellation diagram;

Figure 2 illustrates a typical variation in carrier CSI for a COFDM signal with co-channel analogue television interference;

Figure 3 is a diagrammatic representation of the main components of a demodulator circuit in accordance with the invention;

Figure 4 is an exemplary diagrammatic representation of a

16-QAM constellation diagram, showing the soft decision regions between the points on the constellation grid; and Figure 5 is a flow chart showing the de-mapping method in accordance with one embodiment of the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

An embodiment of the invention will now be described with reference to the accompanying drawings.

Figure 3 is a diagrammatic representation of the main components of a demodulator circuit in accordance with an embodiment of the invention.

The demodulator circuit 100 consists of a de-mapping block 1, a bit and symbol de-interleaving block 2 and a Viterbi decoder 3. The received de-modulated signal 101 is applied to the input of the de-mapping block 1 and the de-mapping block 1 de-maps the received signal and outputs decision data 102 comprising an estimate of the transmitted data together with an indication of the level of confidence to be placed in the estimate. The decision data 102 output from the de-mapping block 1 is input to the bit and symbol de-interleaving block 2. The de-interleaved decision data 103 is input to the Viterbi decoder 3 which generates a demodulated output 104 based on the input decision data.

The de-mapping block 1 comprises a channel state information (CSI) calculation block 11 in addition to a de-mapper 12. The CSI calculation block 11 determines the channel state information for each carrier used in the multi-carrier modulated signal. The channel state information calculated by the CSI calculation block 11 is used by the de-mapper 12 to generate decision data for a received signal using that carrier in a manner dependent on

the channel state information for the respective carrier.

Specifically if the channel state information for the carrier is such that the de-mapper 12 can establish that the SNR on the channel is relatively good (i.e. the channel is fairly quiet), the de-mapper 12 may generate decision data in which the soft decision data is selected in dependence on the distance to nearest constellation point. In contrast, if the channel state information for the carrier is such that the de-mapper 12 can establish that the SNR on the channel is relatively bad (i.e. the channel is fairly noisy), the de-mapper 12 may generate decision data in which the soft decision data is selected in dependence on the channel state information.

In accordance with the invention, therefore, the channel state information is incorporated by the de-mapper 12 in the decision data, and all the CSI functions are contained within the de-mapping block 1. As a result it is not necessary to pass channel state information through the de-interleaving process to the Viterbi decoder as separate information, resulting in reduced data path widths and reduced power requirements.

The channel state information may be calculated in a number of ways in accordance with the invention. However an advantageous method for calculating the channel state information in the CSI calculation block 11 will now be described with reference to Figure 4.

Figure 4 shows a constellation grid for a 16 QAM system, which is described herein as an exemplary transmission system. As is known to a skilled person, each constellation point A on the constellation diagram represents the phase/amplitude characteristic of an

expected signal (i.e. a possible transmitted signal). However the actual received signal is normally different from the expected constellation part, as indicated by the received signal point B.

In accordance with the advantageous embodiment of the invention described with reference to Figure 4, in order to estimate the CSI for each carrier, the separation of the received signal point B from the nearest possible transmitted constellation point A in the I/Q signal space is evaluated and is accumulated over a number of received signals for that carrier.

In accordance with an embodiment of the invention, the quantized distances d_I and d_Q in the I and Q axis directions between the received signal point B and the nearest constellation point A are calculated and for each carrier are summed over a number of symbols received on that carrier. The accumulated value can be used as a measure of the SNR, i.e. as the channel state information (CSI) for that carrier.

In a particularly advantageous embodiment of the invention, the actual distance from the received point B to the nearest constellation point A is calculated for each received symbol and the channel state information for a particular carrier is determined by accumulating this distance over a number of symbols received for that carrier.

Clearly, the channel state information can be also be established by using averaging or other combination techniques on the distances measured for the individual received symbols.

The value established in accordance with the method described above can be taken as a measure of the CSI of the channel, since when the channel is relatively noisy the signal point B corresponding to the received symbol is likely to be at a greater distance in the I/Q plane from the expected constellation points A than when the channel has less noise.

Thus there is described above an advantageous method of calculation of the CSI which can be used advantageously in the prior art demodulator circuits as well as in the demodulator circuit of the present invention.

The CSI value established as outlined above is advantageously used in the establishment of the soft decision data to be used during de-mapping of the data in the de-mapping block 1 shown in Figure 3.

An exemplary method for de-mapping data in the de-mapping block 1 shown in Figure 3 using channel state information calculated as described with reference to Figure 4 will now be described with reference to Figure 5.

Firstly, the CSI value for the channel carrying a signal to be demodulated is compared with a first threshold T1 (step S1). If the CSI value is less than the first threshold T1, the carrier can be considered to have a good signal to noise ratio, and therefore it can be expected that the received constellation points should be close to the transmitted constellation points. In this situation, therefore, the input signal may be de-mapped in accordance with known techniques according to the position of the received signal in the constellation grid and soft decision data representing the quantized distance between the received constellation point and the expected constellation

point may be assigned to the de-mapped bits (step S2).

If the CSI value is greater than the first threshold T1 in step 1, the CSI value is compared to a second, higher, threshold T2 in step S3. If T1< CSI value < T2, the carrier can be considered to have a slightly worse signal to noise ratio. In this situation, the signal is de-mapped to the nearest constellation point, and soft decision data for each de-mapped bit is assigned in dependence on the position within the Gray coding, for example (step S4). Since symbols having similar most significant bits are grouped together in a Gray coding constellation diagram, more confidence can be placed in the most significant bits of the received symbol than in the least significant bits.

If the CSI value is greater than the second threshold T2 in step S1, the CSI value is compared to a third, yet higher, threshold T3 in step S5. If T2 < CSI value < T3, the carrier can be considered to have a relatively bad signal to noise ratio, and therefore although data is de-mapped using the nearest constellation part, each data bit is given soft decision data indicating the lowest possible confidence level (step S6).

Finally, if the CSI value is greater than the third threshold T3, the carrier can be considered to have a sufficiently bad signal to noise ratio that no reliance can be placed on the decoded bits. In this situation all data bits are punctured (step S7).

It will be clear to the skilled person that while the invention has been described with reference to the use of thresholds with which to compare the calculated CSI, the use of thresholds is not essential to the invention.

Although as described above a high value of CSI indicates a noisy channel, it is possible that a measure of CSI is used in which a low value of CSI indicates a noisy channel. In this situation adjustments to the relative magnitudes of the thresholds T1, T2 and T3 and to the method described above with reference to Figure 5 would be required, as would be clear to a skilled person.

Alternatively, in a particularly advantageous embodiment of the invention, soft decision data for the de-mapped data may be generated in the de-mapper by initially generating first data based on the distance between the received signal point and the nearest expected constellation point and then by altering said first data, depending on the channel state information for that carrier, to obtain the soft decision data.

This method is particularly advantageous when implemented in an arrangement in which the separation of the received signal point and the nearest expected constellation point is determined to establish the channel state information for that carrier, since the calculation of the separation of the received signal point and the nearest expected constellation point can be used both in the generation of the soft decision data and also to update the channel state information for that carrier.

Thus a preferable demodulator circuit and method for demodulating a multi-carrier modulated signal using channel state information is disclosed.

CLAIMS

1.
A demodulator circuit for demodulating a multi-carrier modulated received signal, having

a de-mapping means for de-mapping the received signal to generate decision data, the decision data being generated in a manner dependent on channel state information for a respective signal carrier; and

a decoder for decoding received bits from the decision data received from the de-mapping means.

2.
A demodulator circuit as claimed in claim 1 wherein when the channel state information for the respective signal carrier indicates that the channel for that carrier is relatively good, the decision data is generated based only on the received signal, and when the channel state information for the respective signal carrier indicates that the channel for that carrier is relatively bad, the channel state information affects the decision data generated.

3.
A demodulator circuit as claimed in claim 2 wherein when the channel state information for the respective signal carrier indicates that the channel for that carrier is relatively good, the decision data generated comprises an estimate of the bit to be decoded together with soft decision data derived from the difference between the received signal and the expected signal.

4.
A demodulator circuit as claimed in claim 2 or 3 wherein

when the channel state information for the respective signal carrier indicates that the channel for that carrier is relatively bad, the decision data generated comprises an estimate of the bit to be decoded together with soft decision data derived from the difference between the received signal and the expected signal and/or from the channel state information.

5.

A demodulator circuit as claimed in one of claims 2-4 wherein when the channel state information for the respective signal carrier indicates that the channel for that carrier is sufficiently bad that the data is not to be relied on, the decision data generated by the de-mapping means is punctured.

6.

A demodulator circuit as claimed in any preceding claim also comprising means for estimating channel state information for the carriers of the multi-carrier modulated signal.

7.

A demodulator circuit as claimed in claim 6 in which the channel state information for each carrier is estimated from the displacement of the received signal from the expected signal for a plurality of signals received on that carrier.

8.

A demodulator circuit as claimed in claim 7 in which the channel state information for each carrier on which is modulated a symbol is estimated by determining displacement on I and Q axes in the I/Q plane for a plurality of symbols received on that carrier.

9.
A demodulator circuit as claimed in any preceding claim wherein the decoder is a Viterbi decoder.

10.
A demodulator circuit as claimed in any preceding claim wherein the received signal is a COFDM signal.

11.
A digital television receiver comprising a demodulator circuit as claimed in claim 10.

12.
A receiver circuit for receiving a multi-carrier modulated signal, comprising means for establishing channel state information for the carriers of the multi-carrier modulated signal from the displacements of received signals on that carrier from the corresponding nearest expected signal, over a number of received signals.

13.
A method for demodulating a multi-carrier modulated received signal, comprising the steps of:

de-mapping the received signal to generate decision data, the decision data being generated in a manner dependent on channel state information for the respective signal carrier; and

decoding received bits from the decision data received from the de-mapping means.

14.
A method as claimed in claim 13 wherein when the channel state information for the respective signal carrier indicates that the channel for that carrier is relatively

good, the decision data is generated based only on the received signal, and when the channel state information for the respective signal carrier indicates that the channel for that carrier is relatively bad, the channel state information affects the decision data generated.

15.

A method as claimed in claim 14 wherein when the channel state information for the respective signal carrier indicates that the channel for that carrier is relatively good, the step of generating decision data comprises a step of estimating the bit to be decoded together with soft decision data derived from the difference between the received signal and the expected signal.

16.

A method as claimed in claim 14 or 15 wherein when the channel state information for the respective signal carrier indicates that the channel for that carrier is relatively bad, the step of generating decision data comprises a step of estimating the bit to be decoded together with soft decision data derived from the difference between the received signal and the expected signal and/or from the channel state information.

17.

A method as claimed in one of claims 14-16 wherein when the channel state information for the respective signal carrier indicates that the channel for that carrier is sufficiently bad that the data is not to be relied on, the decision data generated by the de-mapping means is punctured.

18.

A method as claimed in any one of claims 14-17 also comprising a step of estimating channel state information

for the carriers of the multi-carrier modulated signal.

19.

A method as claimed in claim 18 in which the channel state information for each carrier is estimated from the displacement of the received signal from the expected signal for a plurality of signals received on that carrier.

20.

A method as claimed in claim 19 in which the channel state information for each carrier on which is modulated a symbol is estimated by a step of determining displacement on I and Q axes in the I/Q plane for a plurality of symbols received on that carrier.

21.

A method as claimed in any one of claims 14-20 wherein the decoder is a Viterbi decoder.

22.

A method as claimed in any one of claims 14-21 wherein the multi-carrier modulated signal is a COFDM signal.

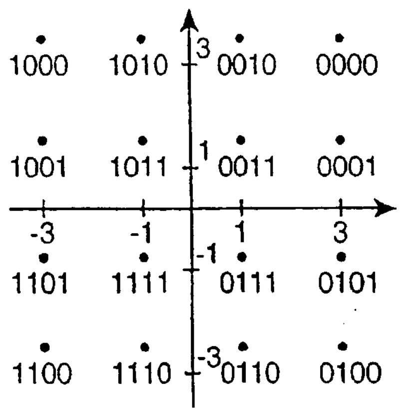
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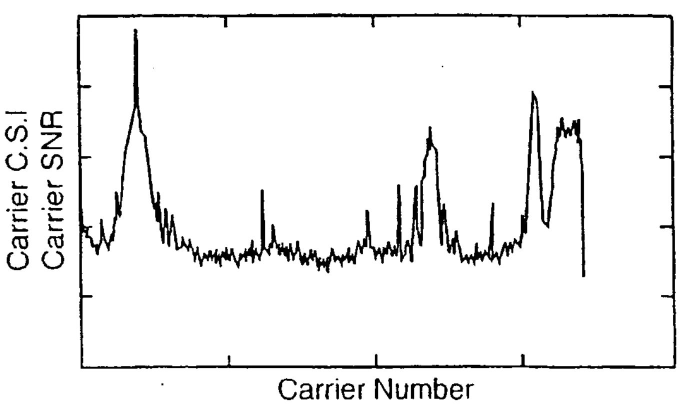
FIG. 1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Carrier SNR
Carrier Number

FIG. 2

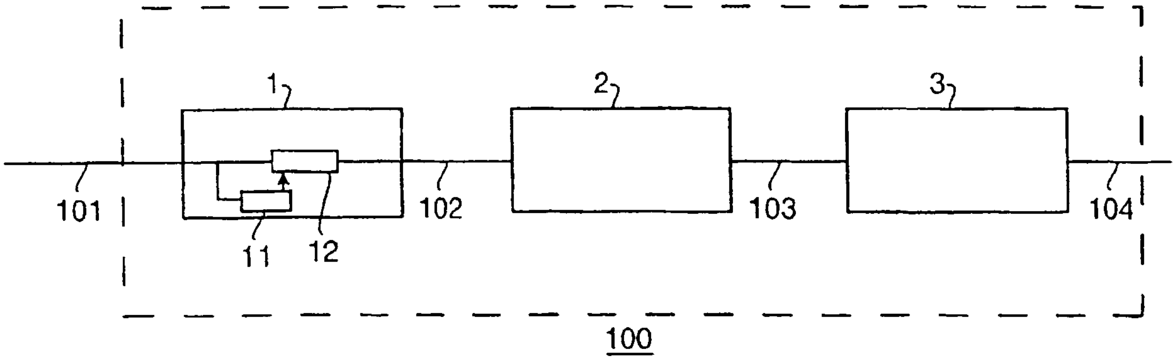

FIG. 3

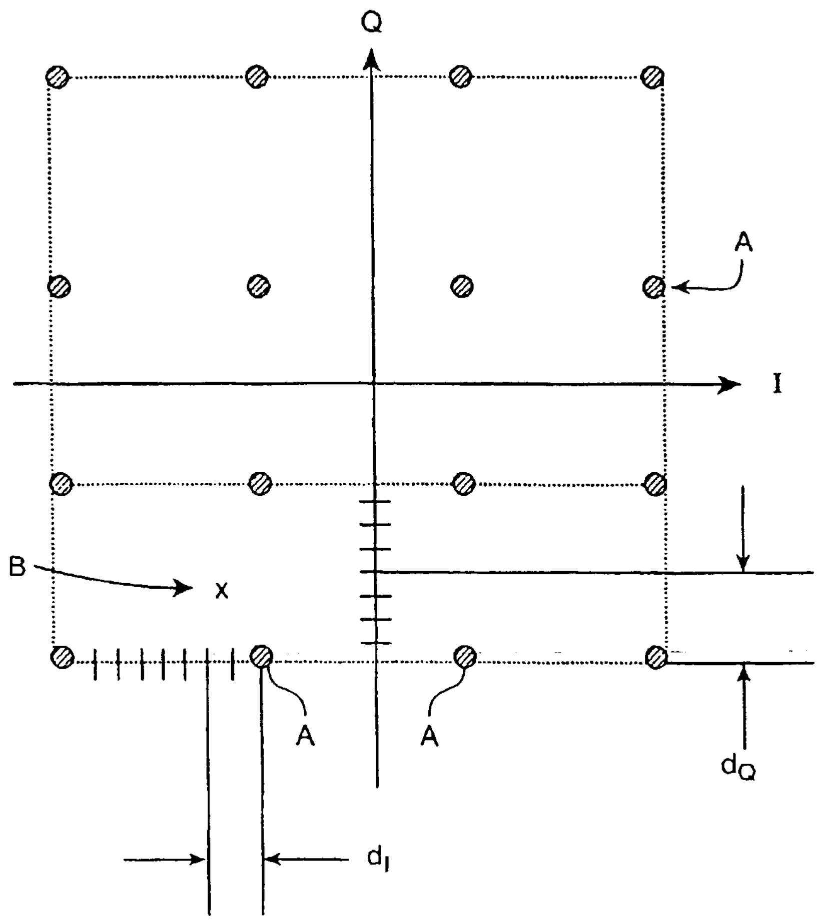

FIG. 4

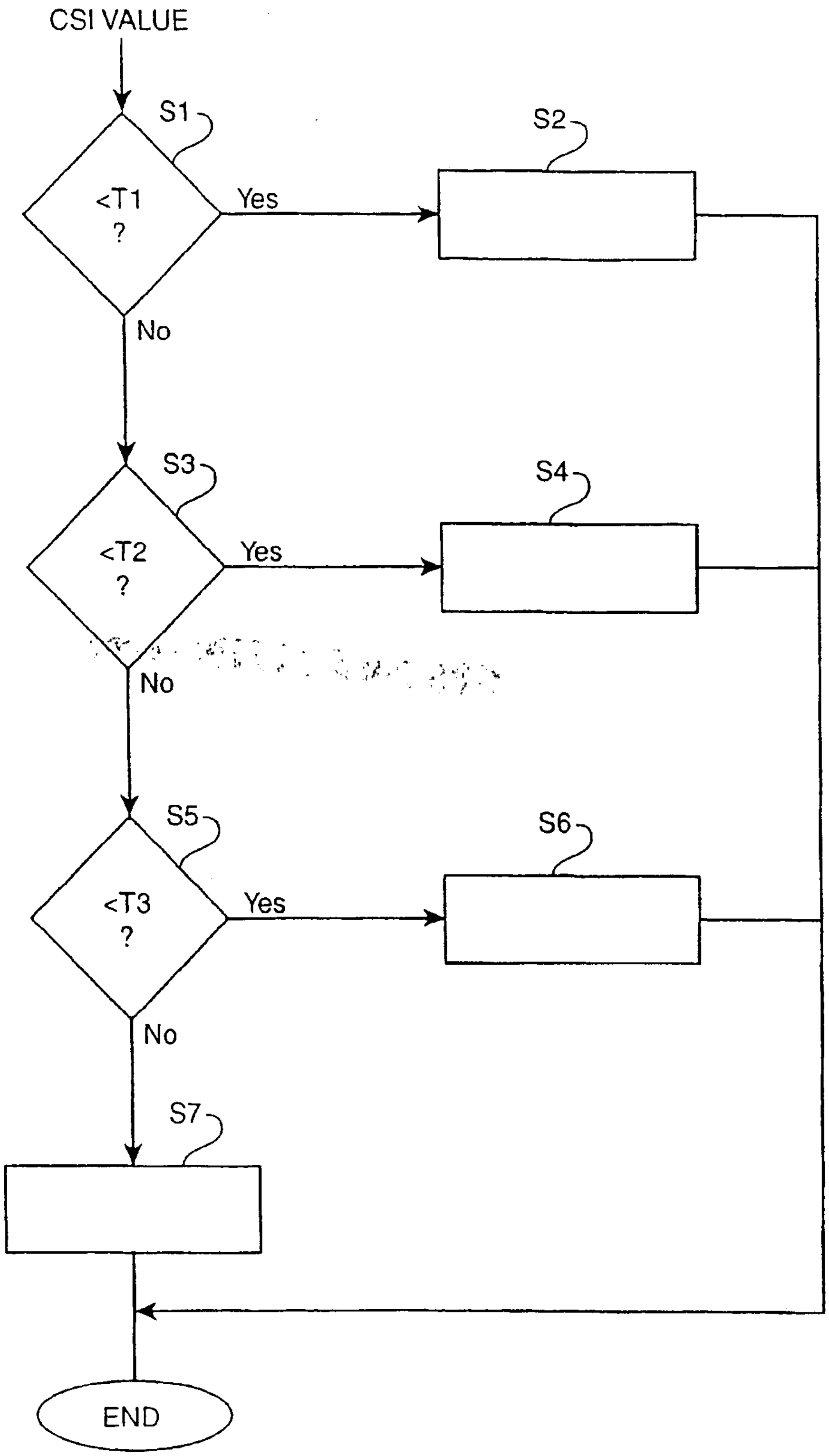

FIG. 5

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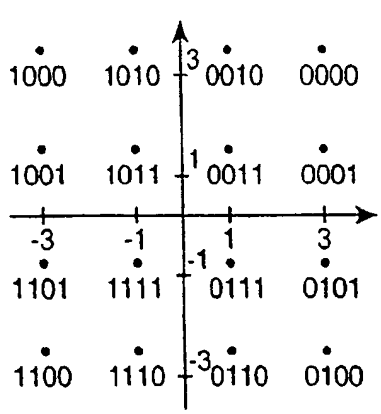
(54) Title: DEMODULATOR CIRCUIT FOR DEMAPPING A MULTI-CARRIER SIGNAL USING CHANNEL STATE INFORMATION



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INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04L27/26 H04L1/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04L H03M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PARK M -Y ET AL: "A DEMAPPING METHOD USING THE PILOTS IN COFDM SYSTEM" IEEE TRANSACTIONS ON CONSUMER ELECTRONICS,IEEE INC. NEW YORK,US, vol. 44, no. 3, August 1998 (1998-08), pages 1150-1153, XP000851633 ISSN: 0098-3063 cited in the application	1,2, 9-11,13, 14,22
Y	the whole document	5-8, 17-20
A		3,4,12, 15,16

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
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X	WEON-CHEOL LEE; CHOUL-HEE CHO; JONG-HO KWAK; MIN-YOUNG PARK; KYUNG-JIN KANG: "VITERBI DECODING METHOD USING CHANNEL STATE INFORMATION IN COFDM SYSTEM" ICCE INTERNATIONAL CONFERENCE ON CONSUMER ELECTRONICS, 1999, pages 66-67, XP002163671	1,2, 9-11,13, 14,21,22
A	the whole document	3,4

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